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SHIPBOARD EMI/EMC TEST REPORT

for the

REDUCED SHIPS-CREW BY VIRTUAL PRESENCE (RSVP) ADVANCED TECHNOLOGY DEMONSTRATION (ATD)

Contract No. N00014-99-C-0033

July 1999

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13. ABSTRACT *(Maximum 200 words)*

EMI/EMC testing was conducted on board the USS Normandy (CG-60), a Ticonderoga Class Aegis Cruiser in early April of 1999. The tests were made to determine a typical electromagnetic operating environment for the RSVP RF Communications System and to perform propagation measurements in the proposed 2.4 GHz ISM band.

The scope of the testing included measurements of the electromagnetic environment from 10 KHz to 3 GHz in three different spaces aboard the ship, and 2.4 GHz propagation measurements in those spaces. The spaces chosen were Main Engine Room 2, Auxiliary Machinery Room 1 and Engineering Crew Quarters.

Of particular interest for the EMI measurements was the band at 2.4 GHz and those surrounding 100 MHz and 10.7 MHz the proposed first and second intermediate frequencies (IFs) for the RSVP receiver.

While the testing revealed no serious problems, it must be remembered that these measurements are only a snapshot in time aboard a single ship. Testing on board different ships may reveal significantly different results.

14. Subject Terms

RSVP, Virtual Presence, Wireless Communication, Compartment Situational Awareness, Shipboard EMI/EMC, Shipboard Radio Propagation

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1. Abstract

EMI/EMC testing was conducted on board the USS Normandy (CG-60), a Ticonderoga Class Aegis Cruiser in early April of 1999. The tests were made to determine a typical electromagnetic operating environment for the RSVP RF Communications System and to perform propagation measurements in the proposed 2.4 GHz ISM band.

The scope of the testing included measurements of the electromagnetic environment from 10 KHz to 3 GHz in three different spaces aboard the ship, and 2.4 GHz propagation measurements in those spaces. The spaces chosen were Main Engine Room 2, Auxiliary Machinery Room 1 and Engineering Crew Quarters.

Of particular interest for the EMI measurements was the band at 2.4 GHz and those surrounding 100 MHz and 10.7 MHz the proposed first and second intermediate frequencies (IFs) for the RSVP receiver.

While the testing revealed no serious problems, it must be remembered that these measurements are only a snapshot in time aboard a single ship. Testing on board different ships may reveal significantly different results.

2. Introduction

A critical part of the RSVP system is the wireless communication network. It must operate reliably in a less than ideal environment inside of ship spaces where there is a lot of machinery and other obstacles disturbing radio wave propagation. In addition, there are many electromagnetic noise and interference sources that could degrade its operation.

The purpose of the shipboard EMI/EMC testing was to determine a typical electromagnetic environment in three different ship spaces in order to find potential interference and noise problems for the RSVP Communication System. These tests were made aboard the USS Normandy (CG-60), a Ticonderoga Class Aegis Cruiser. They were conducted during the period of April 6-8, 1999 off Norfolk, Virginia under conditions where most shipboard systems were operating.

Since the operating frequency band for RSVP is planned to be the 2.4 GHz ISM band, this was of the most interest. Also, since the present RSVP receiver design uses IFs of approximately 100 MHz and 10.7 MHz, the bands surrounding these frequencies were also of critical interest.

The EMI/EMC measurements were made over several bands spanning the range 10 KHz to 3 GHz using a set of antennas and a spectrum analyzer. The entire band was included in order to have a point of reference should interference problems develop in the sensors or in data and signal processing electronics.

This report describes the test methodology, test environment, pertinent measurement data and the conclusions drawn from the at-sea testing.

The cooperation and assistance of the officers and enlisted crew of the USS Normandy is gratefully acknowledged and sincerely appreciated.

3. Methods, Assumptions and Procedures

A block diagram of the test equipment setup for EMI/EMC testing is shown in Figure 1. The measurement instrument is a Hewlett Packard spectrum analyzer Model 8662B. It has a measurement frequency range of 10 kHz to 22 GHz. The antennas are a collection of different types designed to cover sub-bands in the range 10 kHz to 3 GHz. The low frequency antenna (10 kHz to 30 MHz) was inoperative however, so the UHF tunable dipole was used in this range and was therefore acting only as an uncalibrated probe. Its use did however provide some indication of the signals that were present in this range. Figure 2 is a photo of Jack Ford of Draper in Main Engine Room 2 making EMI measurements using the 30-300 MHz biconical antenna.

Scans of the engine room control panel and a switching power supply cabinet were made using a close-field probe for the sense antenna. The probe was moved along the seams of each cabinet and over meters and switches. A photo of the scanning of the control panel in Main Engine Room 2 is shown in Figure 3. Frank DiTizzio of NSWC is shown assisting Jack Ford. These measurements showed that no appreciable interference in the frequency bands of interest was emanating from either system.

Basic Measurement Procedure:

1. Find a suitable location within compartment.
2. Set up equipment for first frequency band.
3. Scan selected band using "Max Hold" instrument state for approximately 10 minutes.
4. Record resulting scan on plotter.

5. Repeat for each frequency band.
6. Measure frequency band around 2.4 GHz (+/-10 MHz) and record results.

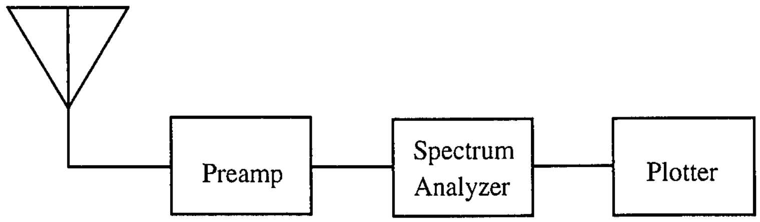

Figure 1. EMI/EMC Measurement Block Diagram

A block diagram of the test equipment setup for the 2.4 GHz propagation measurements is shown in Figure 4. The signal generator is a Hewlett Packard 8660B set to 2.41 GHz. The antennas used are either a broadband discone (800 MHz – 3 GHz) or a 2.4 GHz Toko Patch Antenna (Model DAC 2450CTI). The receiving setup is the same as used for the EMI/EMC measurements. 2.42 GHz is used instead of 2.40 GHz because a signal at 2.40 GHz was detected during the EMI/EMC measurements and would have interfered with the test. This signal later proved to be leakage of the 4^{th} harmonic of the spectrum analyzer's 2^{nd} LO frequency of 600 MHz. A picture of the transmitter (HP Signal Generator) in Main Engine Room 2 is shown in Figure 5.

Basic Measurement Procedure:

1. Setup signal generator and antenna in location remote from EMI/EMC test setup.
2. Set generator frequency to 2.42 GHz and output level to +10 dBm (no modulation).
3. Measure and record received signal at EMI/EMC set setup.
4. Repeat for transmit level of 0 dBm (the planned RSVP transmit power level).

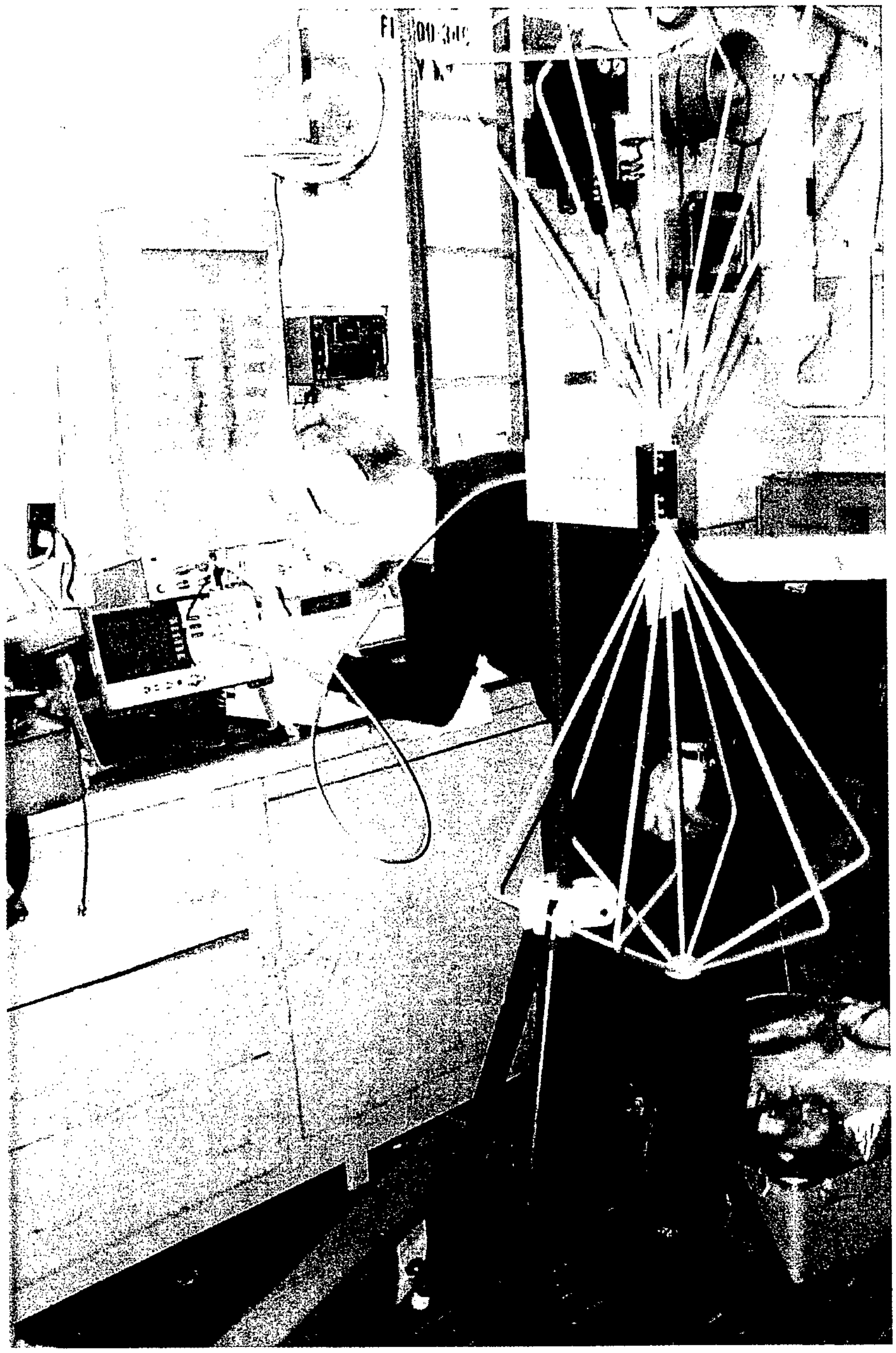

Figure 2. EMI Measurements – Main Engine Room 2

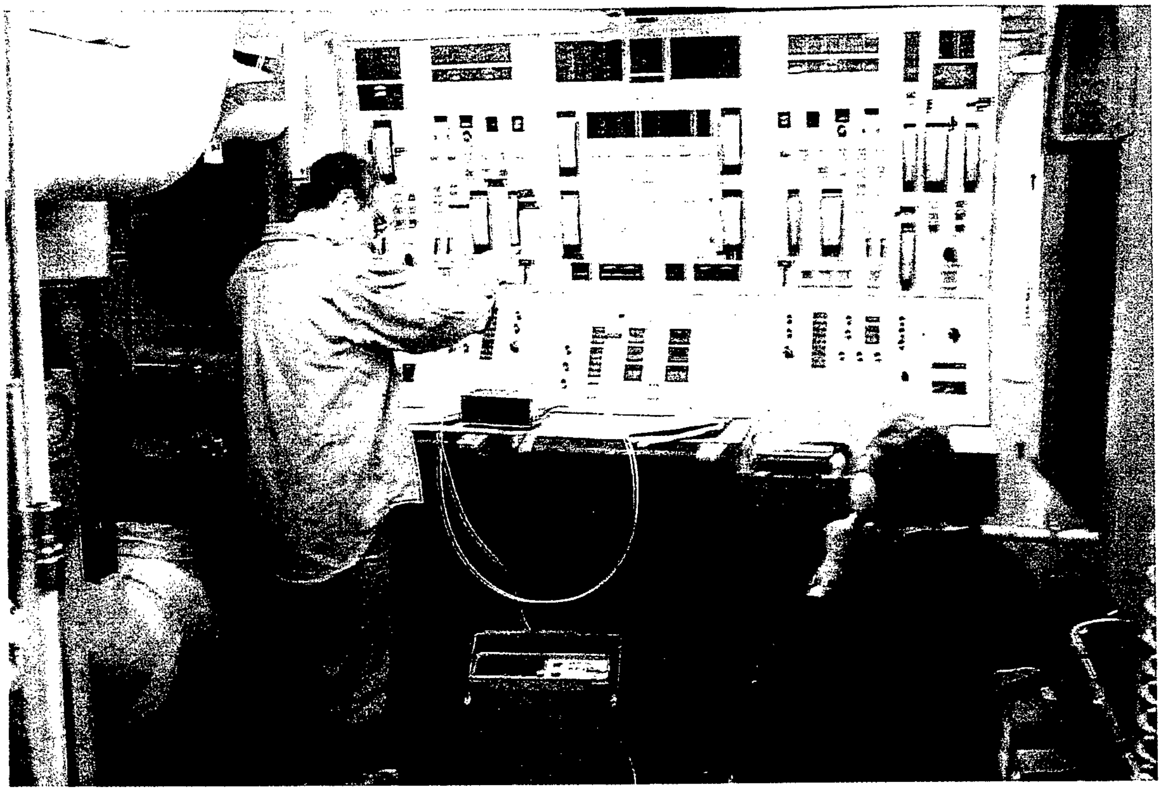

Figure 3. Main Engine Room 2 Control Panel Scan

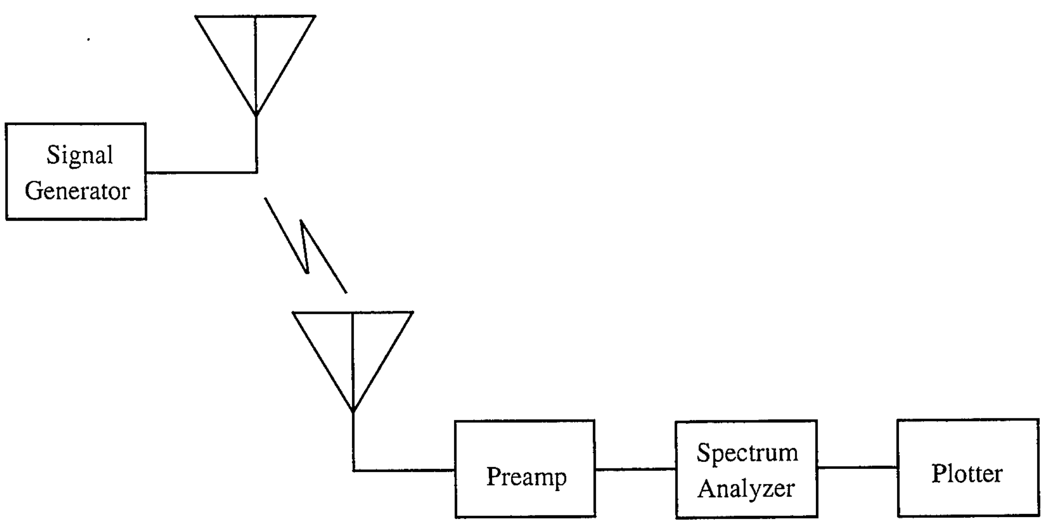

Figure 4. Propagation Measurement Block Diagram

Figure 5. Transmitter in Main Engine Room 2 (Toko Antenna)

4. Results and Discussion

4.1 Interference Measurements

4.1.1 RSVP Operating Frequency Band (2.4 GHZ)

Since the unmodulated carrier at 2.4 GHz was later proven to be LO harmonic leakage from the spectrum analyzer, the 2.4 GHz band was found to be clear of any interference during the testing on the Normandy. Again, this is a snapshot in time on a single ship, but the results are certainly encouraging for the planned RSVP wireless communication system. As shown in the 600 MHz to 3 GHz scans in Appendix A, the closest possible interferer is about 60 MHz below 2.4 GHz and should not cause any problems.

4.1.2 RSVP 1st IF (110.5 MHz)

The highest signal level near the 1st IF (110.5 MHz) was found in the Engineering Crew Quarters. The 30 MHz to 300 MHz scan in Appendix A shows this measured level to be about -5 dBm. Backing out the 30 dB preamplifier gain, the actual level is -85 dBm. Since 1st IF signal levels are expected to be approximately -110 dBm on average, such an interferer could be significant. Careful shielding of the receiver and filtering of power and control lines is therefore required. Signals measured near 110.5 MHz in other spaces were significantly lower in amplitude.

4.1.3 RSVP 2nd IF (10.7 MHz)

No significant signals were found within +/-1 MHz of 10.7 MHz. It must be remembered however, that the antenna used for these measurements was a UHF dipole which was effectively an uncalibrated probe at this frequency. It is therefor possible that signals which were actually present might not have been detected.

In any case the interference potential would seem to be low. The shielding necessitated by the 110.5 MHz interference will protect against radiated interference at 10.7 MHz as well. The line filtering (already required) need only be designed to provide the needed attenuation at 10.7 MHz.

4.2 Propagation Measurements

Measurements of radio wave propagation at 2.4 GHz were made in Main Engine Room 2 and Auxiliary Machinery Room 1 using the measurement setup shown in Figure 4. Since time did not permit an extensive series of measurements, an attempt was made to perform those which we thought might represent a "worst case". The longest transmission paths, and those with the largest and greatest number of obstructions were therefore chosen within each room.

Figure A6 in Appendix A shows the signal received in a measurement made in Main Engine Room 2 over an obstructed path across it's diagonal of approximately 20 Meters. A signal-to-noise ratio (SNR) of approximately 30 dB is shown with the spectrum analyzer's resolution bandwidth set to 10 kHz.

If we assume a transmission bandwidth of 200 kHz for the desired RSVP data rate of 200 kbit/sec and that the noise bandwidth for the measurement is equal to the analyzer's resolution bandwidth of 10 kHz, then the resulting Eb/No is equal to:

$$Eb/No = 30\text{ dB} - \{10\text{Log}\,(200\text{ kHz}/10\text{ kHz})\}\text{ dB} = (30 - 13)\text{ dB} = 17\text{ dB}$$

For non-coherent detection of binary FSK this would give a bit error rate (BER) of approximately 10exp-6 (at 14 dB Eb/No) with a 3 dB margin. The noise power density (No) of this measurement is determined by the 3 dB noise figure of the preamplifier. A higher RSVP receiver noise figure would directly reduce the received SNR, dB for dB.

While this is a measurement over just one transmission path, it does illustrate that communication at the desired rate of 200 kbit/sec is indeed possible in a near "worst case" scenario. In an implemented system, several access points would be used in a space as large as Main Engine Room 2. This would mitigate the presence of obstructions and reduce the "free space" loss which is a function of distance, thereby increasing the average received SNR. Other propagation measurements within the two rooms produced similar results.

5. Conclusions

The EMI/EMC Shipboard Tests on the USS Normandy have produced encouraging results. Interfering signals in the desired 2.4 GHz ISM band were found to be non-existent in the ship spaces measured. Other spaces on the ship such as the galley with its microwave ovens, may produce quite different results. Immunity to microwave oven emissions must be a consideration in RSVP signal design.

Interfering signals near the RSVP receiver's 1st IF were found to be of sufficient strength to be a potential problem, without careful shielding of the receiver and filtering of its power and control lines. These design measures, with consideration for the lower frequency of 10.7 MHz should be sufficient to control any interference sources near the 2nd IF also.

The propagation tests showed that communication at the desired data rate of 200 kbit/sec can be achieved under near "worst case" conditions providing the receiver's noise figure is sufficiently low. Under actual operating conditions with several access points, SNR's should be significantly higher on average.

While these tests provide good reasons for continuing with the present design approach, subsequent testing may require modifications to that approach. Design flexibility must be incorporated from the beginning wherever possible.

6. Recommendations

Based on the results of the shipboard EMI/EMC testing, the following actions are recommended:

1. The RSVP radio must be packaged in a shielded RF enclosure with particular attention paid to receiver shielding effectiveness at 110.5 MHz and 10.7 MHz.
2. The RSVP radio must incorporate adequate power and control line filtering at 110.5 MHz and 10.7 MHz.
3. RSVP signal design must include a mitigation strategy for microwave oven interference in the 2.4 GHz ISM band.
4. Perform conducted and radiated emission testing on the RSVP radio when packaging has been completed to determine if additional shielding or filtering of control, power or RF lines is needed to prevent interference to shipboard systems by the RSVP radio.
5. Conduct further propagation testing aboard a Navy ship to determine inter-space propagation and further refine the criteria for access point density.
6. Conduct shipboard testing of packaged RSVP radios using BER metrics for evaluation.

APPENDIX A

SHIPBOARD EMI/EMC DATA

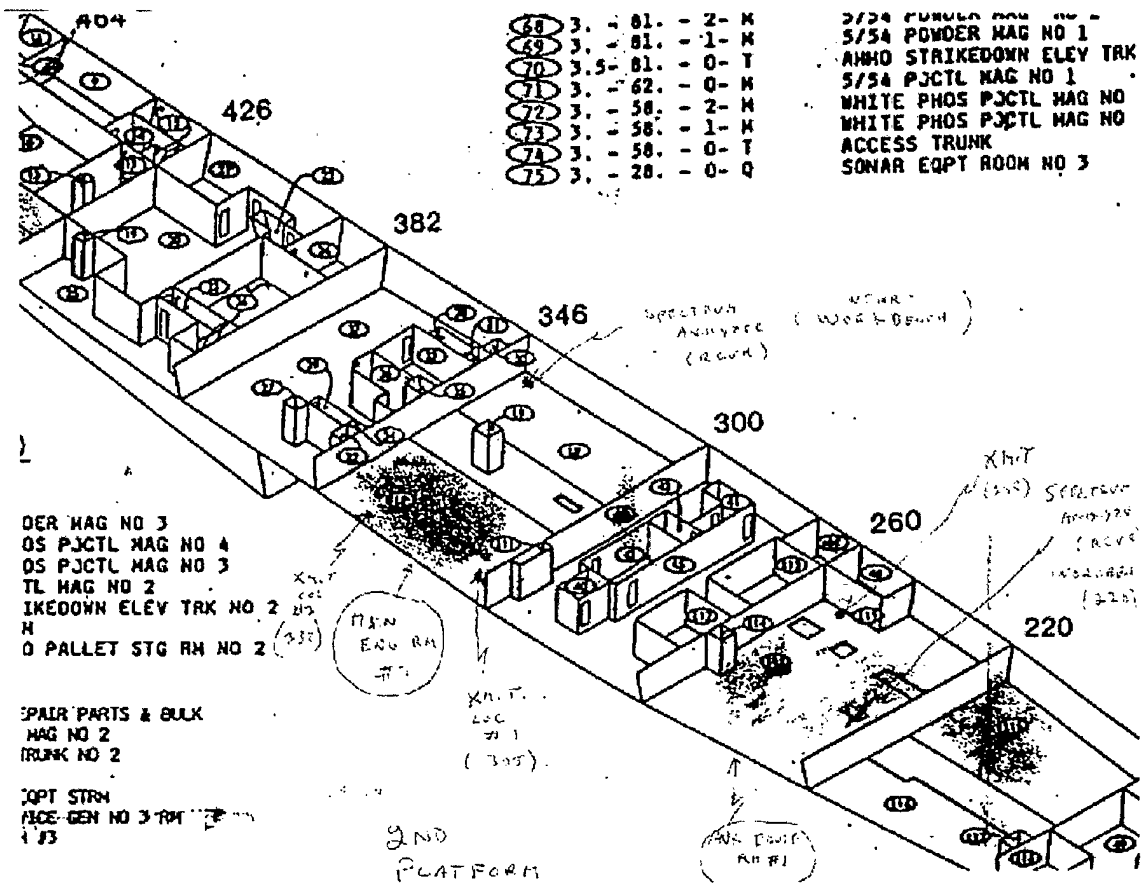

Figure A1. Main Engine Room 2 Measurement Locations

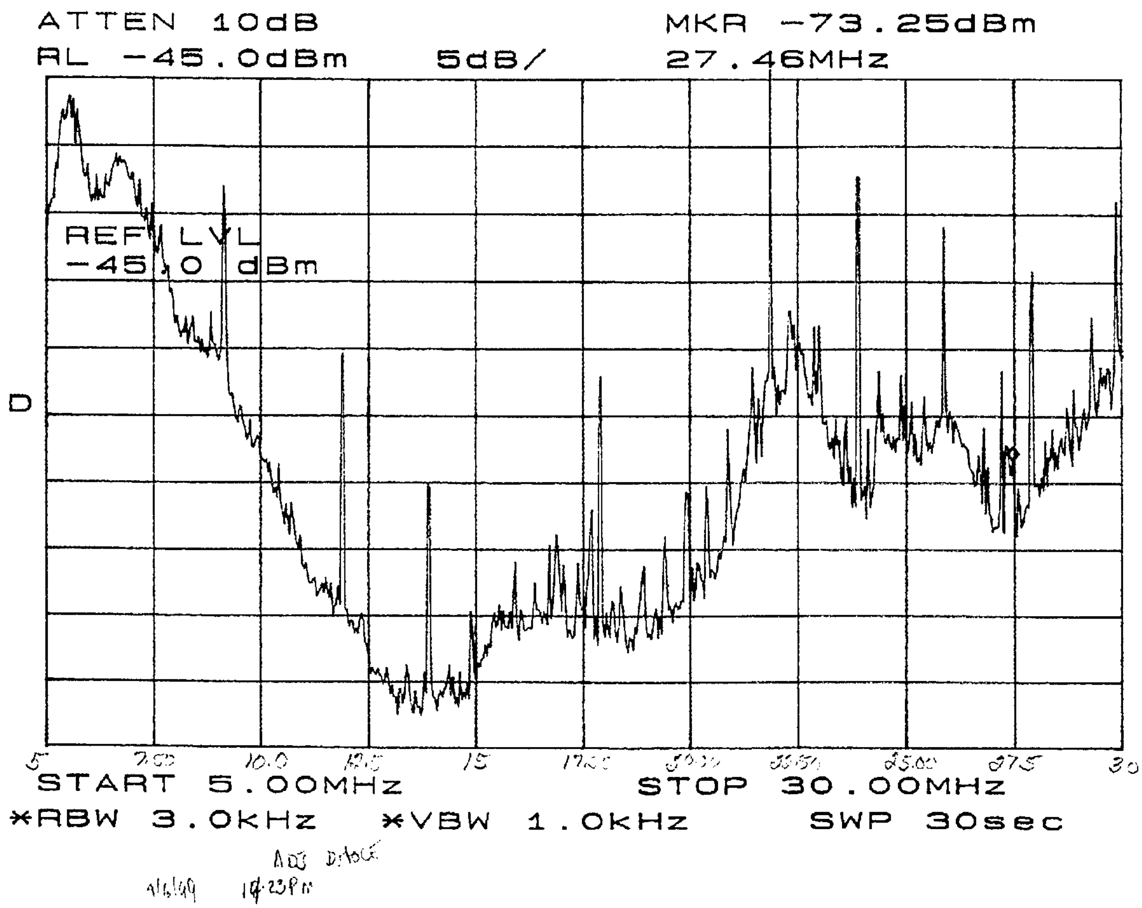

Figure A2. Main Engine Room, 5 MHz – 30 MHz Scan

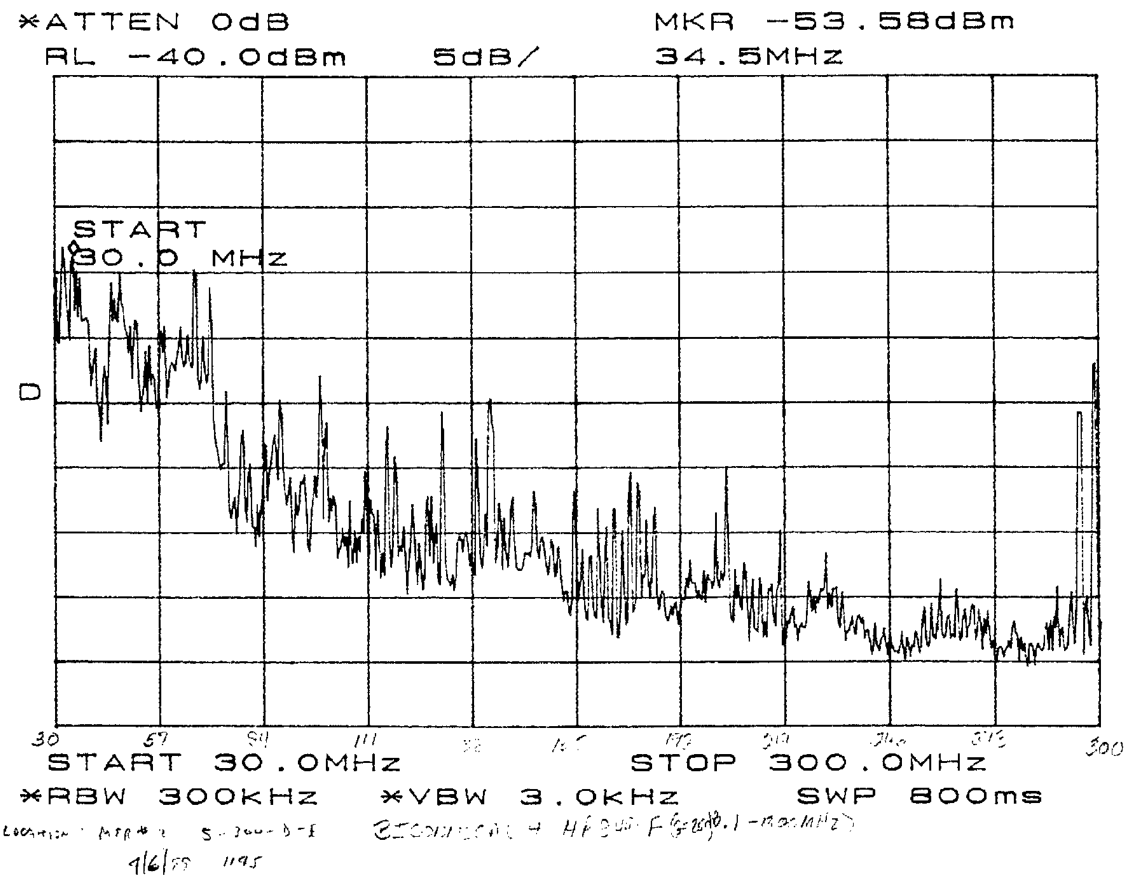

Figure A3. Main Engine Room 2, 30 MHz – 300 MHz Scan

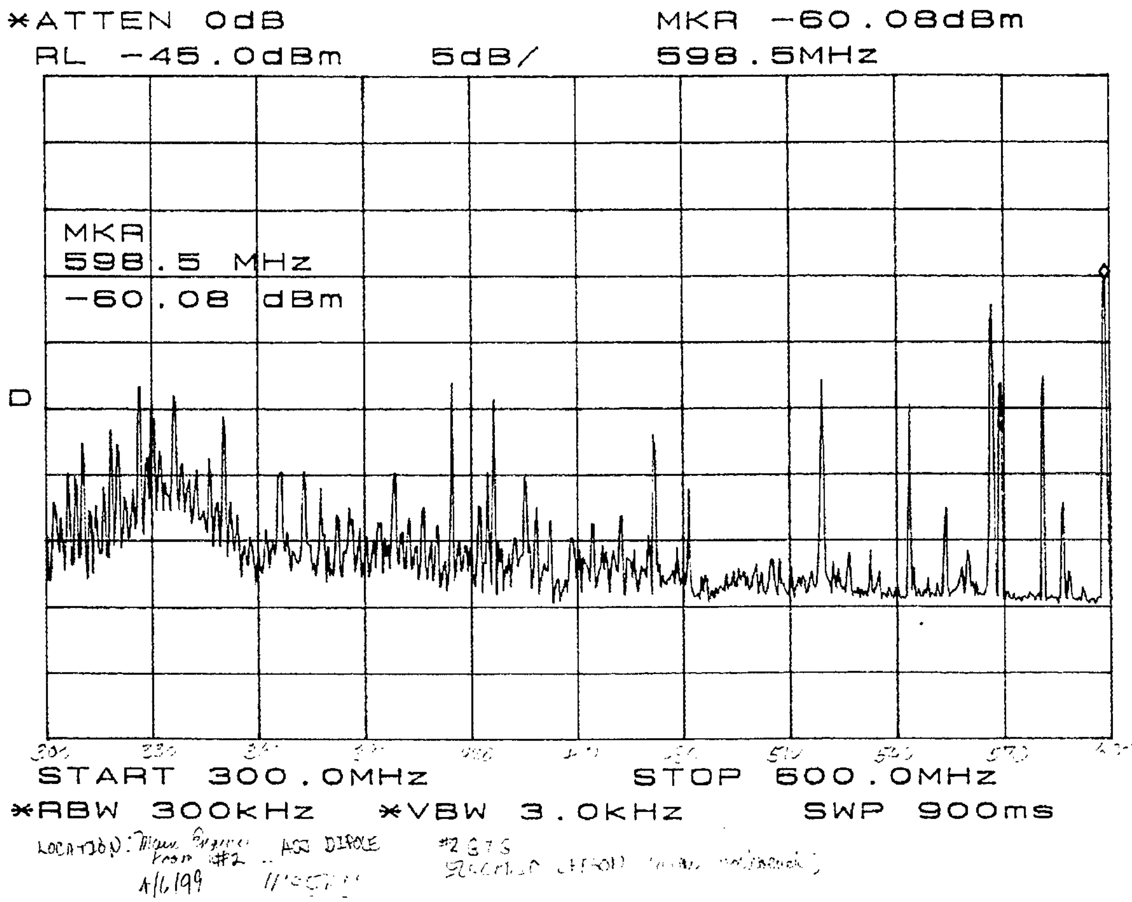

Figure A4. Main Engine Room 2, 300 MHz – 600 MHz Scan

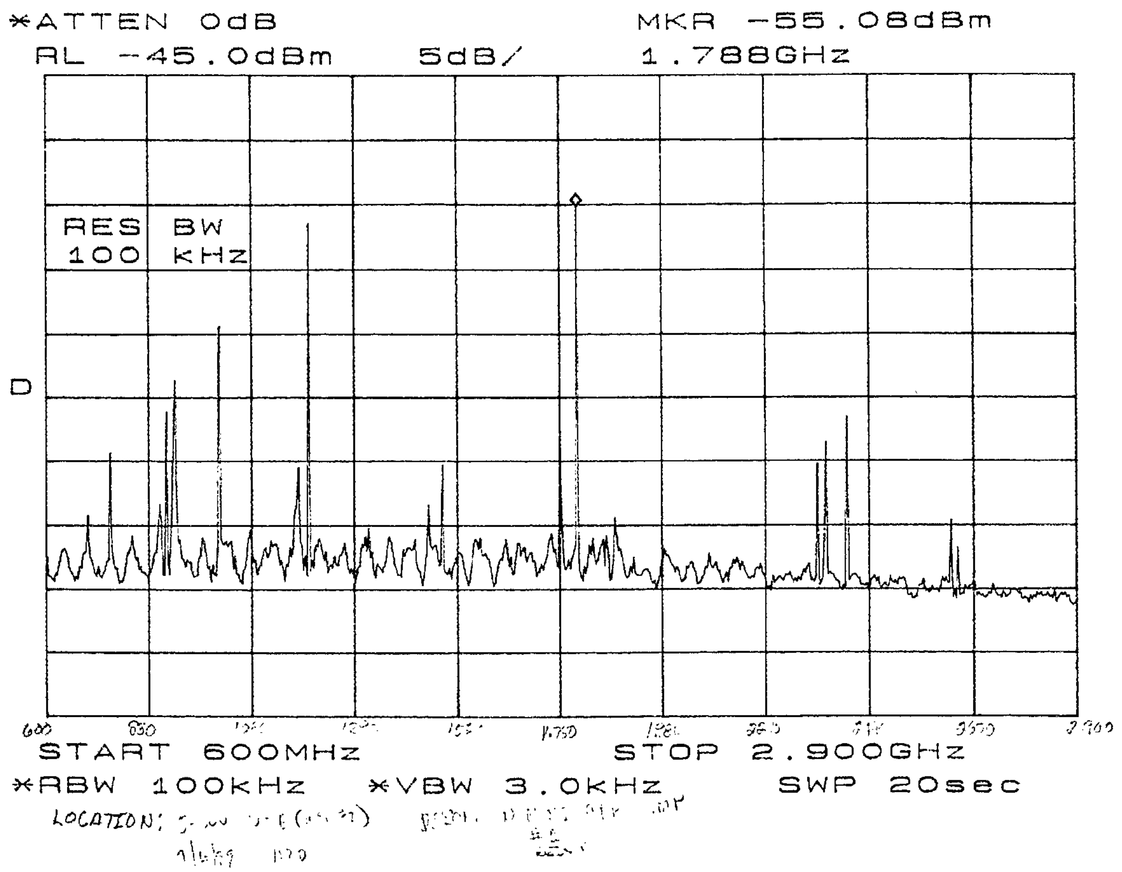

Figure A5. Main Engine Room 2, 600 MHz – 2 GHz Scan

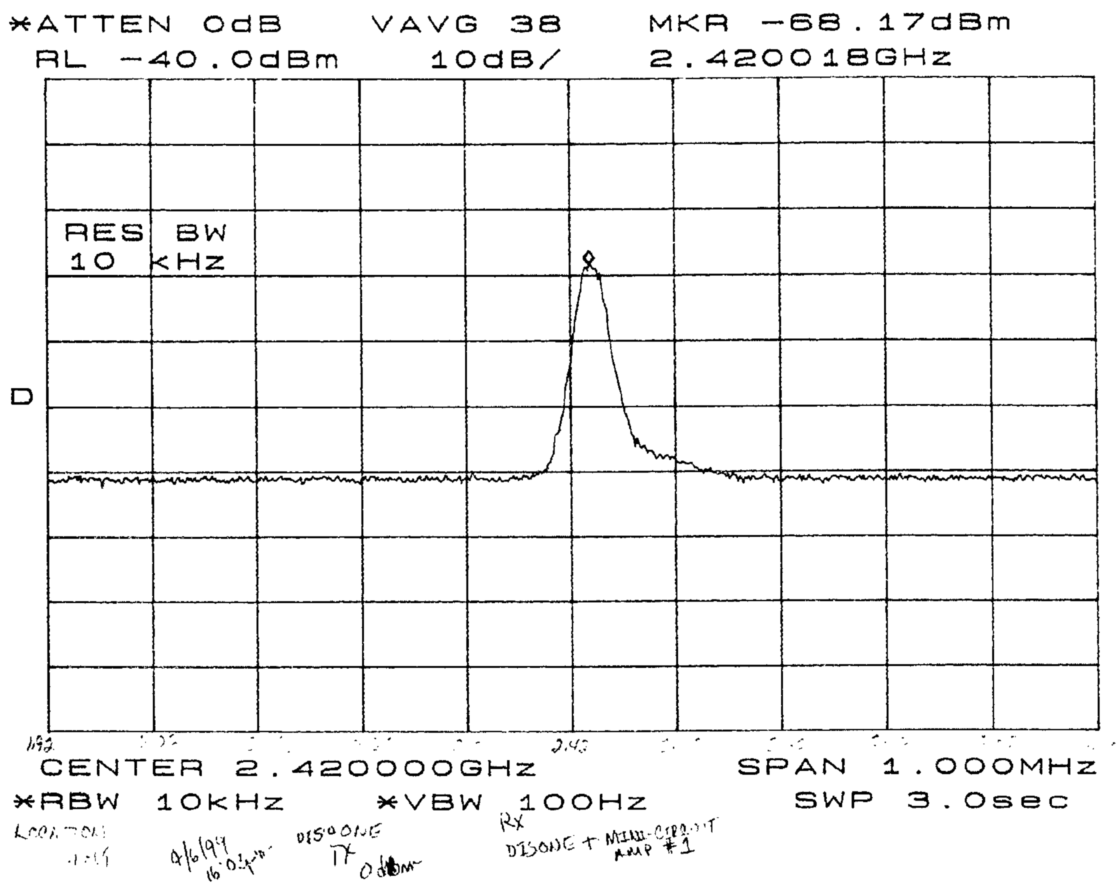

Figure A6. Main Engine Room 2 (ST. 305) to
Workbench Propagation Measurement

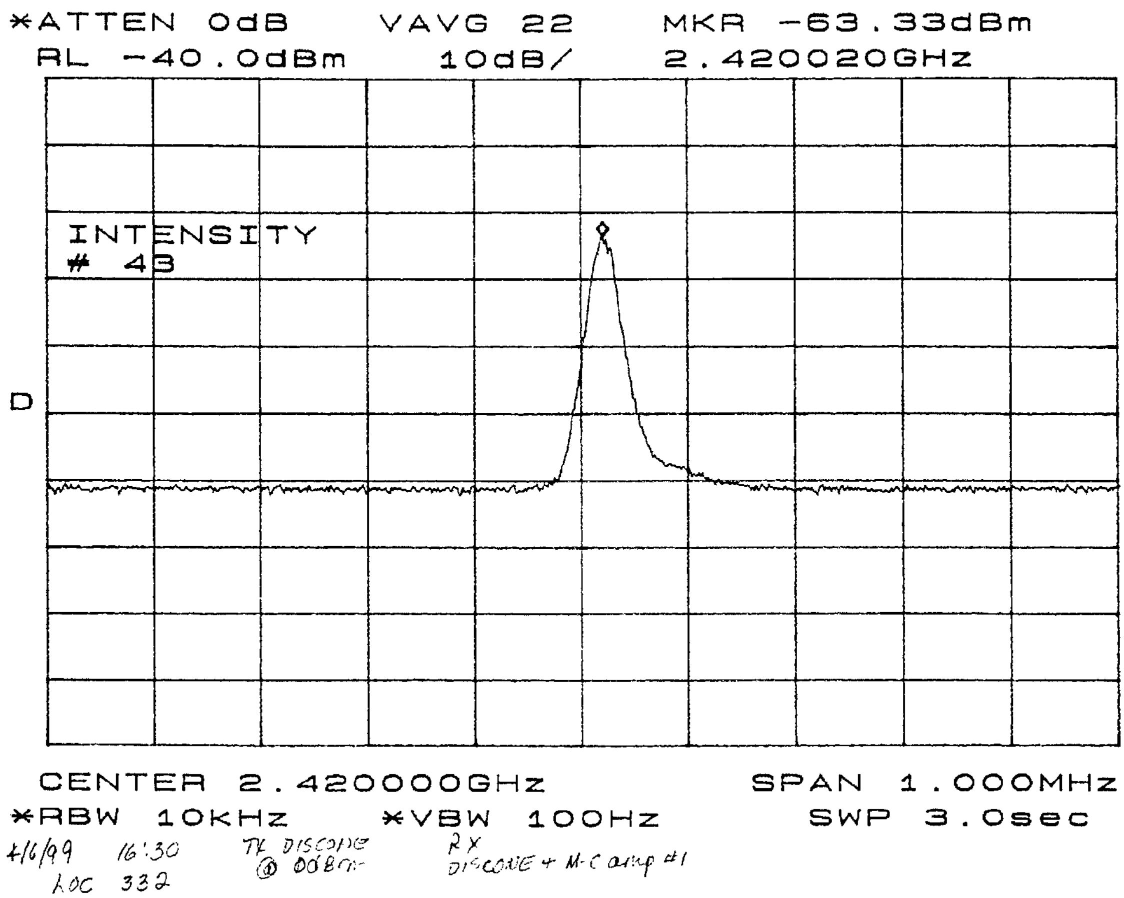

Figure A7. Main Engine Room (ST. 332) to
Workbench Propagation Measurement

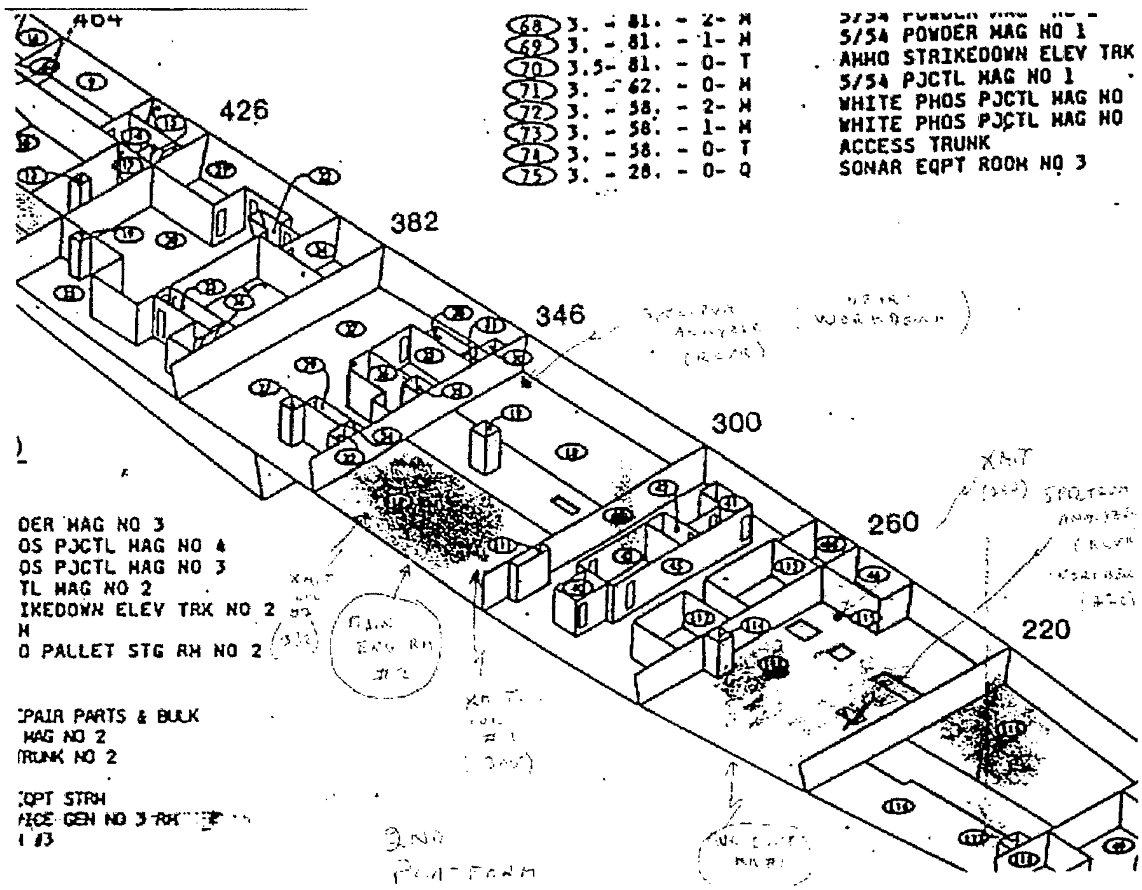

Figure A8. Aux Equipment Room 1 Measurement Locations

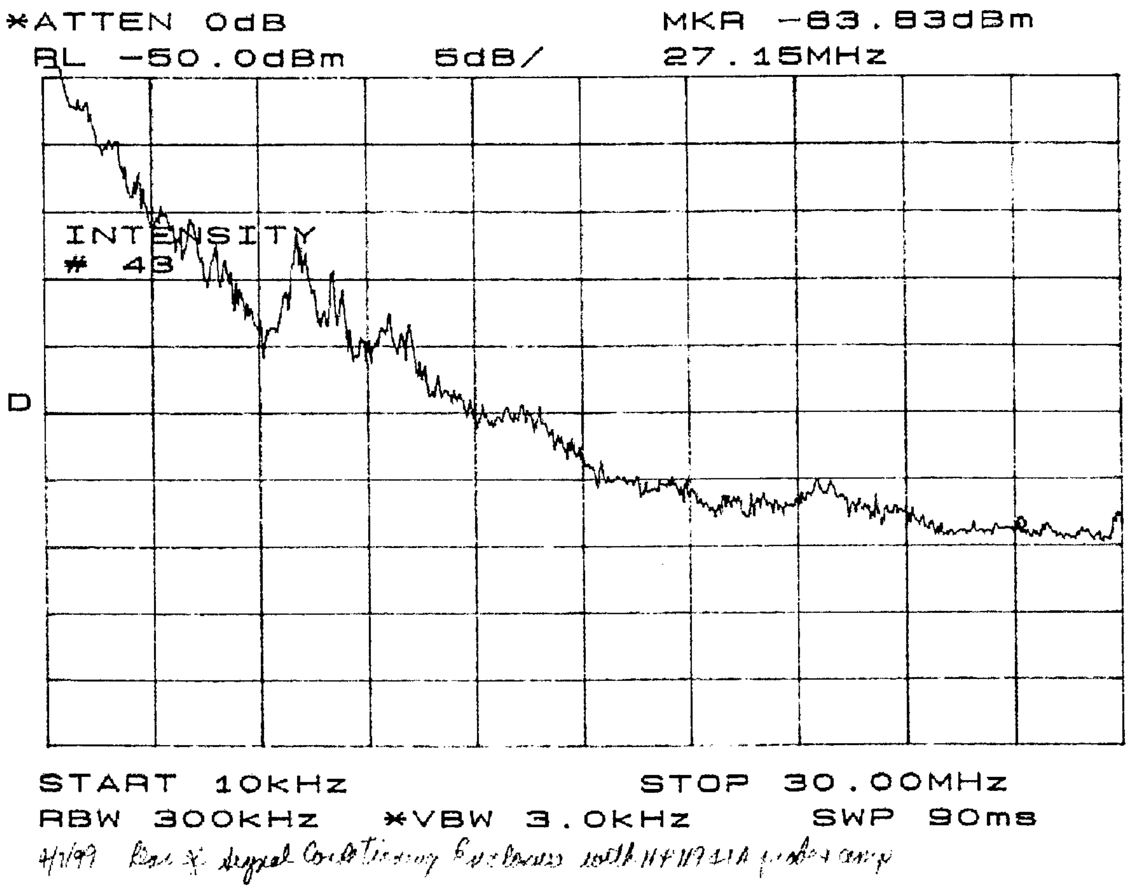

Figure A9. Aux Equipment Room 1, 10 KHz – 30 MHz Scan

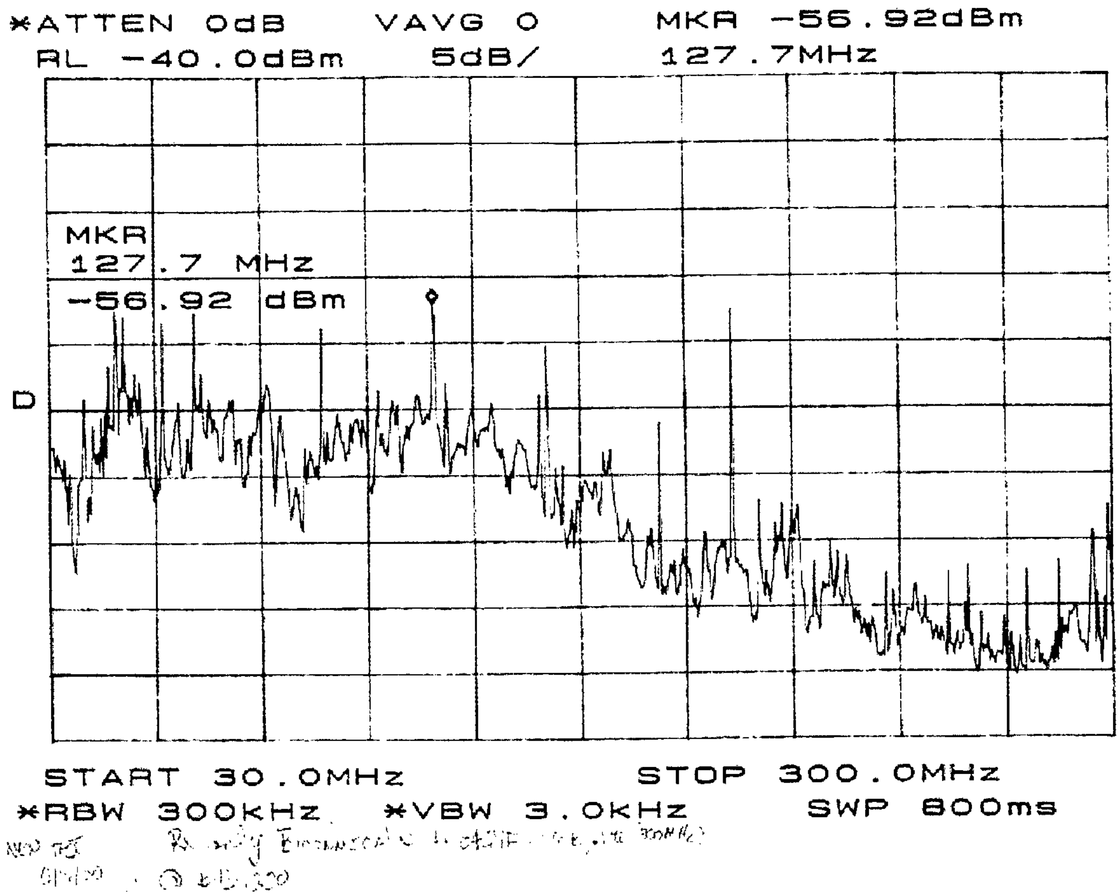

Figure A10. Aux Equipment Room 1, 30 MHz – 300 MHz Scan

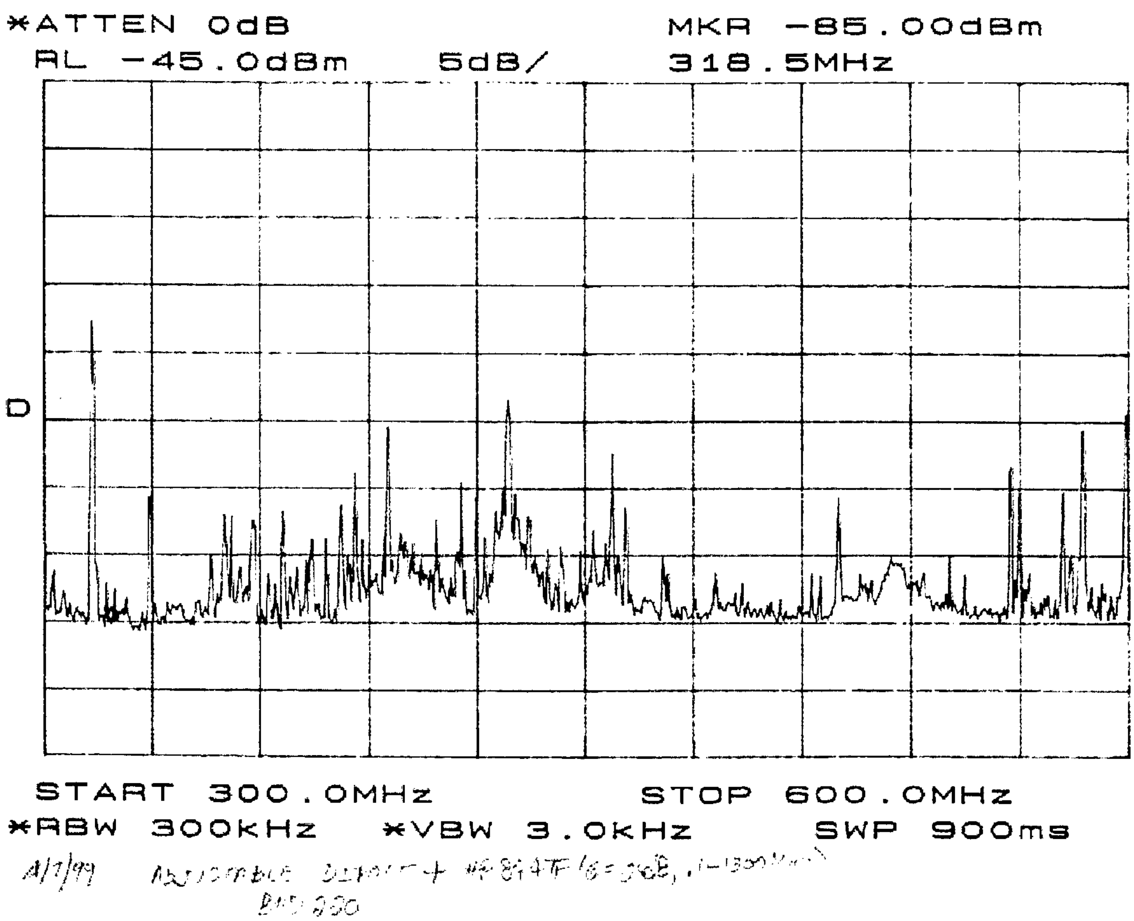

Figure A11. Aux Equipment Room 1, 300 MHz – 600 MHz Scan

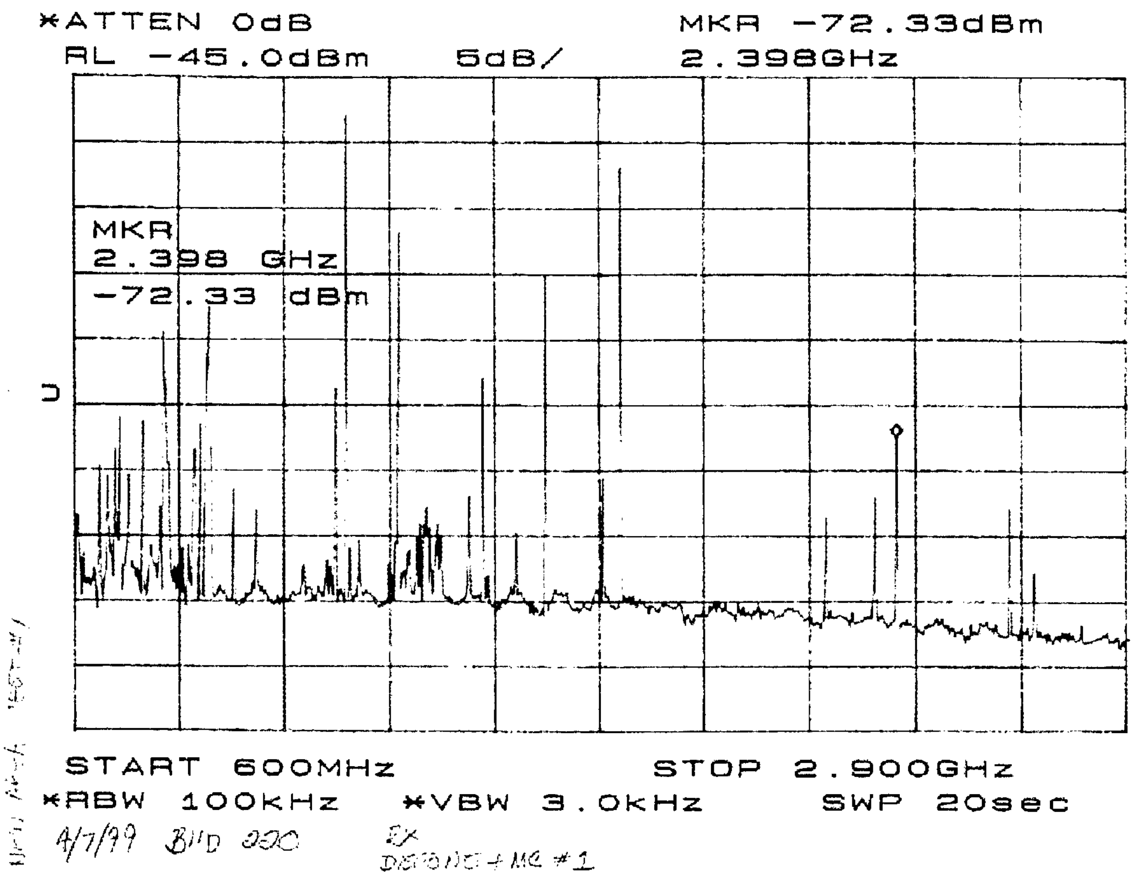

Figure A12. Aux Equipment Room 1, 600 MHz – 2.9 GHz Scan
(Anomalous signal at 2.4 GHz from HP Signal Generator 1st LO)

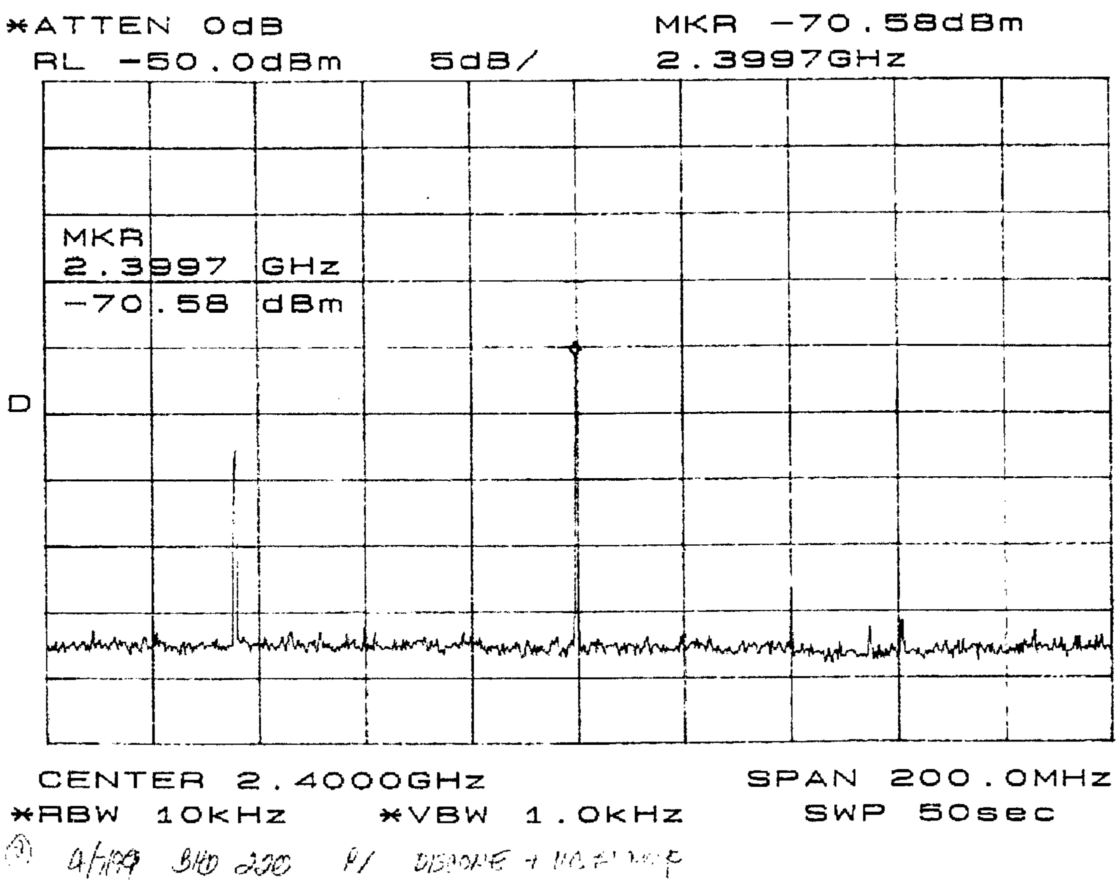

Figure A13. Aux Equipment Room 1, 2.4 GHz Band Scan
(Anomalous signal at 2.4 GHz is from HP Signal Generator 1st LO)

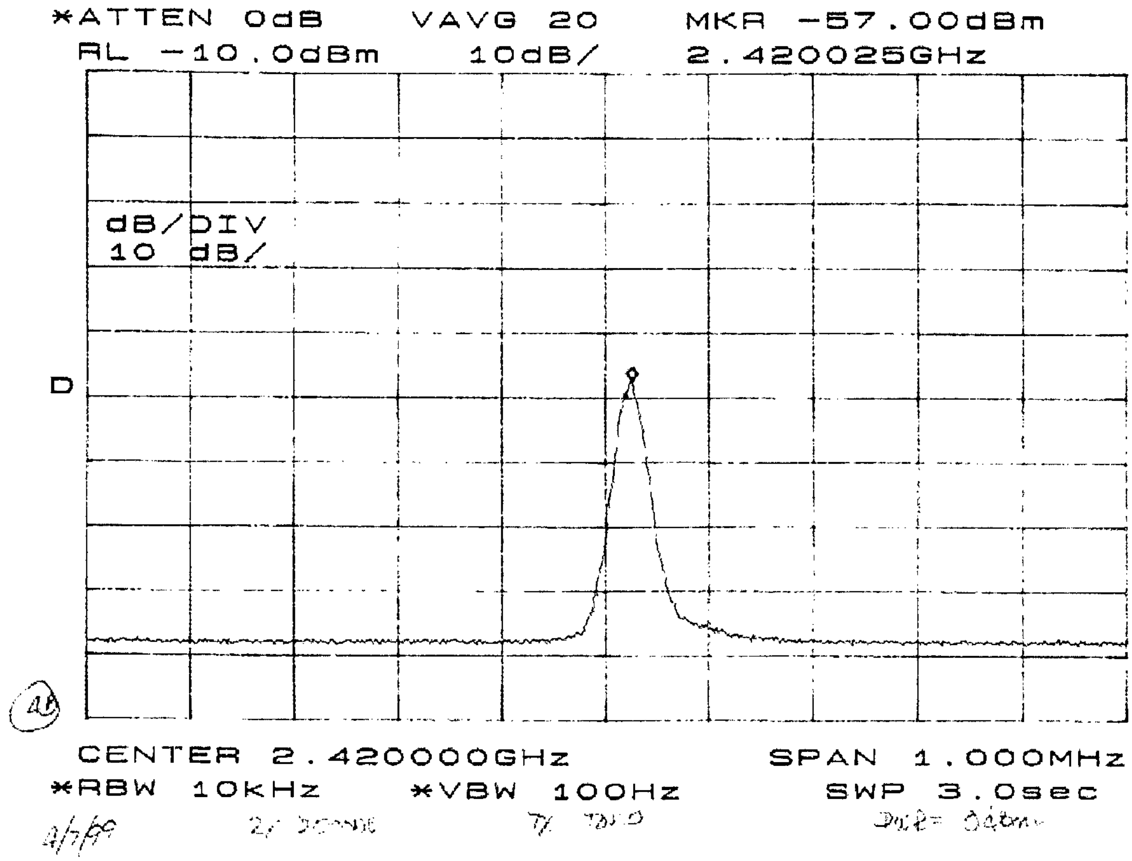

Figure A14. Aux Equipment Room Propagation Measurement (ST-250 to ST-220)

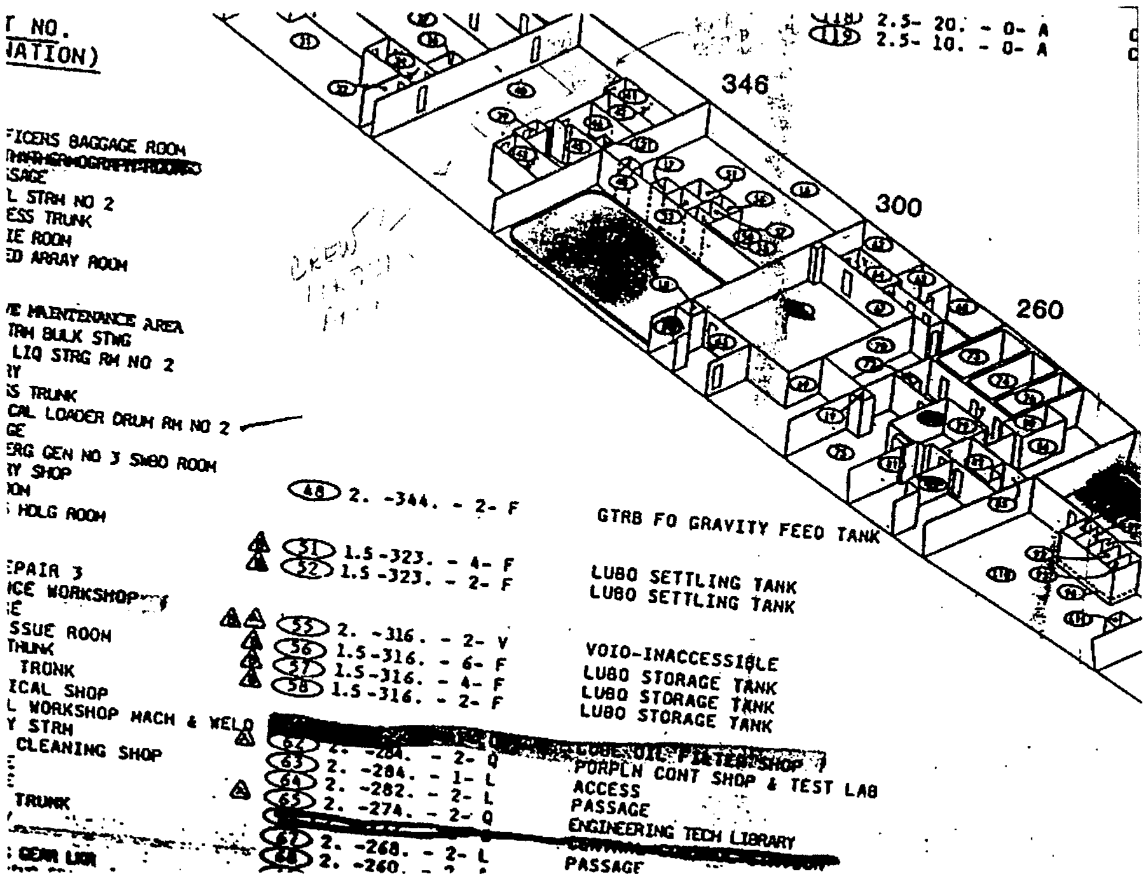

Figure A15. Engineer Crew Quarters Measurement Location

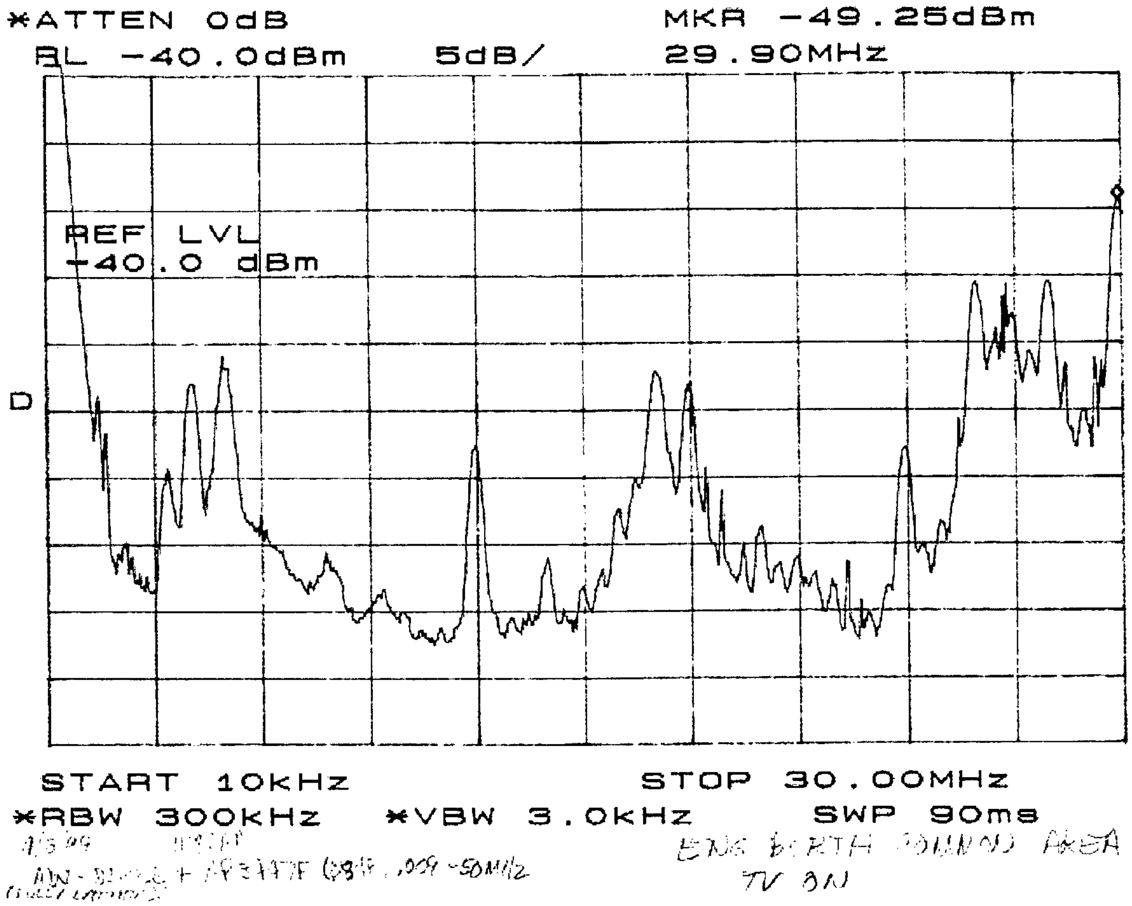

Figure A16. Engineer Crew Quarters 10 KHz – 30 MHz Scan

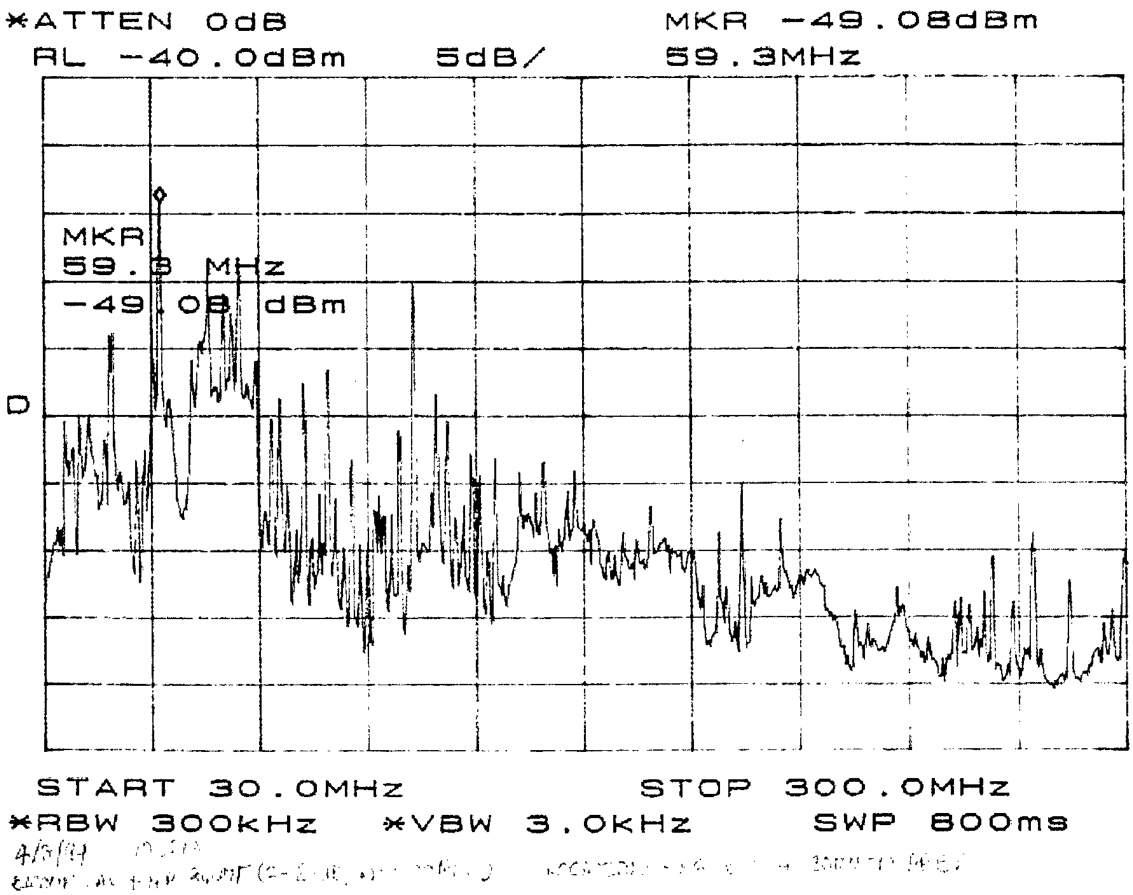

Figure A17. Engineer Crew Quarters 30 MHz – 300 MHz Scan

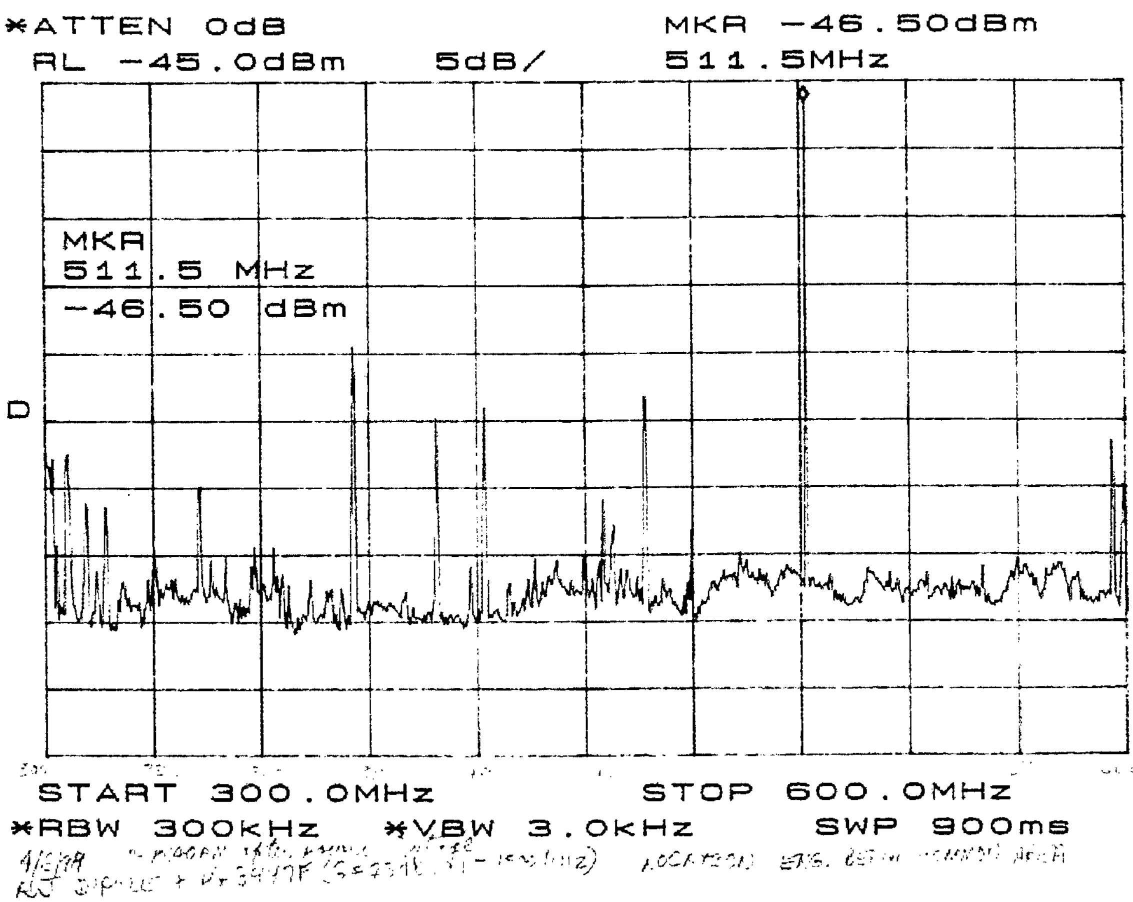

Figure A18. Engineer Crew Quarters 300 MHz – 600 MHz Scan

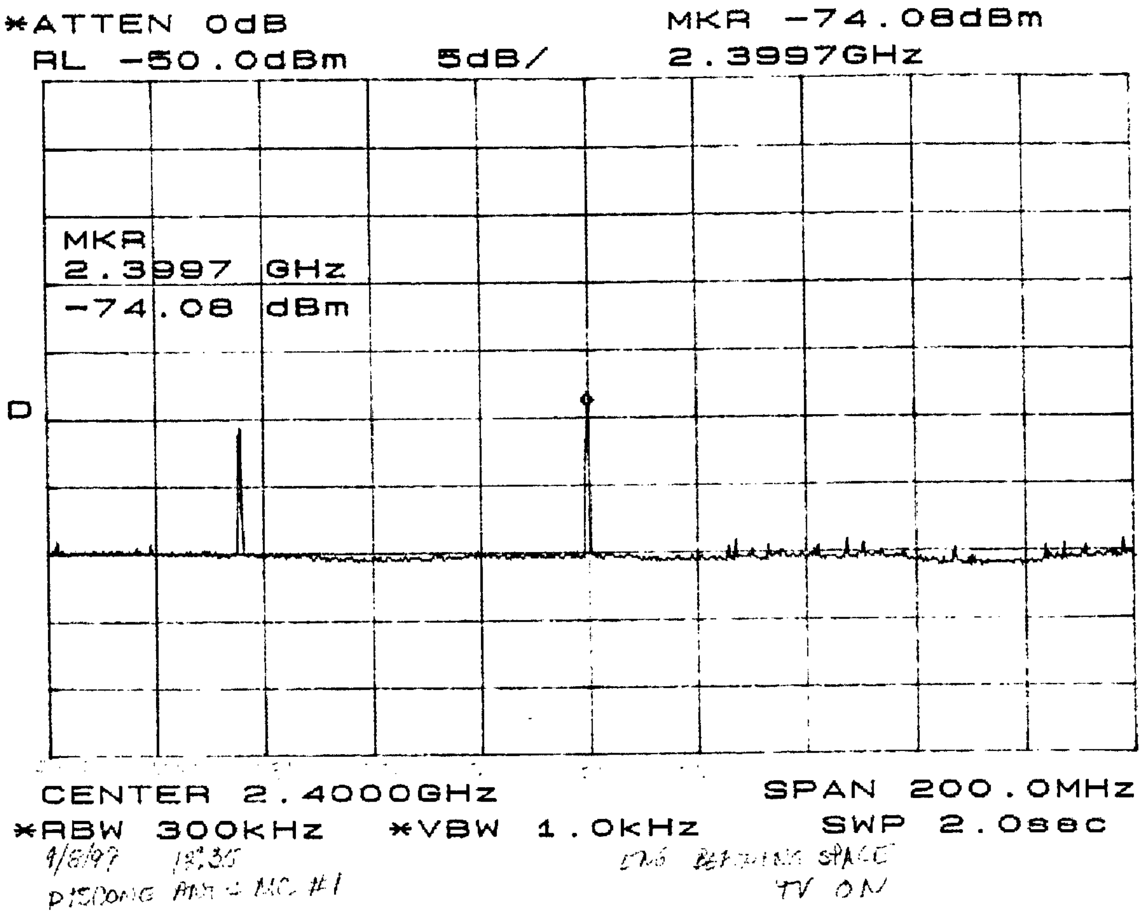

Figure A19. Engineer Crew Quarters 2.4 GHz Band Scan
(Anomalous signal at 2.4 GHz from HP Signal Generator 1st LO)

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Attn: James Gagorik

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SUBJECT: RSVP Shipboard EMI/EMC Test Report

DATE: 19 OCTOBER 1999

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The attached technical report, Shipboard EMI/EMC Test Report for the Reduced Ships-Crew By Virtual Presence (RSVP) Advanced Technology Demonstration (ATD), is submitted in compliance with CDRL A001 of the referenced contract.

APPENDIX B

ACRONYMS

ATD	Advanced Technology Demonstration
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
IF	Intermediate Frequency
ISM	Industrial Scientific and Medical
RF	Radio Frequency
RSVP	Reduced Ships-Crew by Virtual Presence
SNR	Signal to Noise Ratio